Transportation Consortium of South-Central States

Tran-SET

Solving Emerging Transportation Resiliency, Sustainability, and Economic Challenges through the Use of Innovative Materials and Construction Methods: From Research to Implementation

Strategies for Prioritizing Needs for Accelerated Construction after Hazard Events

Project No. 18PPLSU04

Lead University: University of New Mexico

Collaborative Universities: Louisiana State University

Final Report

September 2019

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There is a need for rapid and responsive infrastructure repair and construction after natural disaster events such as hurricanes, wildfires, and tornadoes. These natural disasters often shut down basic infrastructure systems, as experienced recently in several Region 6 states as well as in other states around the country. Accelerated construction practices are often used in these situations to speed up the traditional, and often slow, project delivery process. However, after a natural disaster, several and different types of transportation infrastructure components are in need of inspection, rehabilitation or reconstruction, and transportation agencies are challenged with the task of prioritizing these accelerated projects. This study conducted an extensive literature review of current accelerated methods, infrastructure prioritization practices, and institutional barriers. Interviews with professionals from the transportation industry, including both private and public services, were conducted. Significant input from the railroad industry was used to compare private and public transportation systems responses after disasters. The results of this survey were used to quantify the importance of the accelerate methods and prioritization criteria, and which are the barriers to implement a prioritization model. Lastly, a decision support tool for prioritizing needs for accelerated construction after disaster events, specifically hurricanes and flooding, which commonly affect Region 6, was developed using the data collected.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ABC	Accelerated Bridge Construction
AHP	Analytical Hierarchy Process
CPT	Cumulative Prospect Theory
CSFs	Critical Success Factors
DOM	Disaster Operation Management
DOT	Department of Transportation
EDC	Every Day Counts
EDM	Emergency Decision Making
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
GA	Genetic Algorithm
HFS	Hesitant Fuzzy Set
LVR	Low-Volume Roads
NCDOT	North Carolina DOT
NCHRP	National Cooperative Highway Research Program
NHFN	National Highway Freight network
NHS	National Highway System
NRP	Network Restoration Problem
RI	Recovery Index
STI	Strategic Transportation Investment
STIP	Statewide Transportation Improvement Program
TRC	Total Recovery Cost
TRD	Total Recovery Duration
TxDOT	Texas DOT
UTP	Unified Transportation Program

EXECUTIVE SUMMARY

There is a need for rapid and responsive infrastructure repair and construction after natural disaster events such as hurricanes, wildfires, and tornadoes. These natural disasters often shut down basic infrastructure systems, including roads, bridges, water supply, and power supply, as experienced recently in several Region 6 states as well as in other states around the country. These infrastructure systems are critical systems which the public relies on, and it is important that these systems become operational again as soon as possible.

Accelerated construction practices are often used in these situations to speed up the slow project delivery process. However, after a natural disaster, too many transportation infrastructure types are in need of rehabilitation and/or reconstruction. Transportation agencies are challenged with the task of prioritizing these projects.

Even though the current body of knowledge has investigated accelerated construction and post-disaster project prioritization for transportation infrastructure, the studies do not overlap between accelerated construction, emergency operations, and prioritization of infrastructure projects at a programmatic level for post-disaster recovery. Also, prior studies have not focused on a diverse portfolio of projects and have mostly concentrated on projects with similar characteristics. There is a need for further research and guidance to assist the state Department of Transportation (DOTs) in identifying and prioritizing needs for accelerated construction after hazard events.

This study investigated the current practices and institutional barriers to identify and quantify important decision criteria and to develop a decision support tool for prioritizing needs for accelerated construction after disaster events, specifically hurricanes and flooding which commonly affect Region 6. The input from private owners of infrastructure (specifically, railroad owners in charge or responses to emergencies) and also the information from public entities like Los Alamos County have informed prioritization of tasks after emergencies, based on real emergencies managed by them in the past. The model used in this research project has used their inputs collected by focused interviews. The recommendations of these owners in terms of barriers, accelerated decisions, and prioritization, are added. Future considerations for including owners' inputs are added at the end of this report that will be further explored with both the railroad owners and the Los Alamos County.

1. INTRODUCTION

Transportation infrastructure has been severely affected by recent hurricanes and flooding, for example, after historic flooding in the state of Louisiana in 2016, the Louisiana Department of Transportation and Development reported the closure of approximately 200 roads, including more than 30 washouts of state highways (*1*). Another 1,400 critical bridges needed to be inspected before they could be opened to traffic. Harvey floodwaters in Houston, TX collapsed bridges and washed away roads by eroding their foundations (Figure 1). Highway traffic was disrupted by severe and prolonged inundation.

Figure 1. Bridge Collapse near Rosenberg TX as a result of Hurricane Harvey *(2)*.

Accelerated construction practices are often used in these situations to speed up the traditional, and often slow, project delivery process. However, after a natural disaster, transportation infrastructure components require inspection, rehabilitation, or reconstruction. Transportation agencies are challenged with the task of prioritizing which projects should be tackled first considering resource constraints. The lack of a plan for accelerated transportation projects in response to disaster events increases the recovery time of the transportation network. Therefore, poor response to disasters will not only affect the efficiency of disaster relief operations, but also delay the reconstruction of the local economy. Infrastructure failures can also create additional security issues for the community, exposing them to safety hazards (such as bridge collapse, lack of traffic lights, dangerous routes, etc.), which can lead to crashes and death.

There is a need for rapid and responsive infrastructure repair and construction after natural disaster events such as hurricanes, wildfires, and tornadoes. These natural disasters often shut down basic infrastructure systems, including roads, bridges, water supply, and power supply, as experienced recently in several Region 6 states as well as in other states around the country. These infrastructure systems are critical systems which the public relies on, and it is important that these systems become operational again as soon as possible.

This study will perform a literature review, investigate current practices, and identify institutional barriers to develop a decision support tool for prioritizing needs for accelerated construction after natural disaster events. It should be noted that the report will benefit resiliency and emergency response planners from state DOTs by providing guidance to identify and prioritize needs for accelerated construction after disaster events.

2. OBJECTIVES

To ensure that this research responds to the needs of transportation agencies about prioritizing accelerated construction projects, the following objectives have been established:

- Identify and quantify the importance of decision criteria when prioritizing post-disaster accelerated construction projects. Decision criteria can develop a decision support tool for prioritizing needs for accelerated construction after disaster events.
- Develop a multi-criteria decision-making tool for prioritizing accelerated construction needs after a natural disaster, including the classification of the transportation infrastructure component, primary population served, and resource constraints; and
- Evaluate strategies for accelerating construction in a cost-effective manner post-disaster for a program of critical transportation infrastructure projects.

3. LITERATURE REVIEW

The Federal Highway Administration (FHWA) has embraced the concept of accelerated construction through its Every Day Counts (EDC) initiative, including strategies for accelerated bridge construction (ABC). Most of these strategies, however, relate to the materials used in the construction process once a need has been identified. On the other hand, several studies from the National Cooperative Highway Research Program (NCHRP) have provided guidance for accelerated construction and disaster recovery including NCHRP Scan 07-02: Best Practices in Accelerated Construction Techniques *(3)*, NCHRP Report 662: Accelerating Transportation Project and Program Delivery *(4)* and NCHRP Report 525: Guide for Emergency Transportation Operations (*5*). Although some of the reports lay out challenges and recommendations for pursuing accelerated construction, they do not provide comprehensive guidance on such prioritization. In this section, a comprehensive study on previous researches is organized, and it is divided into two categories as follow: (1) applied methods for prioritization and (2) emergency decision making.

3.1. Identify Prioritization Criteria

Prioritization for transportation construction projects has been applied for different purposes, such as Low-Volume Roads (LVR), road network maintenance, cross-modal projects, and rail projects. Additionally, prioritization has also been used by State DOTs to plan the State and Government Transportation Programs. One example is the Unified Transportation Program (UTP) and the Statewide Transportation Improvement Program (STIP). Finally, prioritization applications include (1) post-disaster conditions, such as road recovery after a natural disaster; (2) optimization of post-disaster reconstruction of transportation networks; (3) post-earthquake restoration process with repair prioritization of highway network system; and (4) bridge retrofit prioritization, which is critical for effective pre-disaster risk mitigation. The prioritization criteria can be divided into different levels: (1) factors and (2) subfactors.

3.1.1. Prioritization for LVR

Stein et al. *(5)* surveyed U.S. State Department of Transportations and Canadian provincial transportation agencies in order to investigate their practices to prioritize the investment for LVR (Table 1.). Their prioritization process usually starts with a combination of engineering data analysis grouped by pavement and bridge management systems. Their research also found that these agencies use different combinations of quantitative and qualitative ratings and scores.

Table 1. General prioritization criteria for Low-Volume Roads (LVR) *(6)*.

Parameters	Criteria
Pavement management systems	• Life cycle costs • User travel time • Safety • Vehicle operating costs
Bridge management systems	• Economic conditions • Social conditions • Environmental conditions

3.1.2. Road Recovery After a Natural Hazard

Chen and Tzeng *(7)* proposed a fuzzy multi-objective model to recover a road-network after an earthquake. Their model used a bi-level solution to prioritize the reconstruction of the assets. In the upper level, three primary criteria were used, then a combination of other criteria was used in the lower level (Table 2). Similarly, Zamanifar and Seyedhoseyni *(8)* developed an algorithm comprised of four modules, together with a fuzzy VIKOR approach to assist in the prioritization of urban roadway recovery after a natural disaster. This model was applied in a municipal zone in Tehran, Iran. Route importance and damage level are used for the model (as shown in Table 2). Their solution considered the insertion of the roadway in the roadway network.

Table 2. Criteria to prioritize road recovery after a natural disaster *(7, 8)*.

Parameters	Criteria
Upper level	• Travel-time for travelers in a road-network during reconstruction • Individual reconstruction time of any work-troop • Idle time between work-troops
Lower level	• Damage points • Available work-troops for reconstruction • All physical links in a post-quake road-network • The time needed for work-troop to reconstruct damage point completely • Travel time for work-troop to move from a well-constructed point to another damage point • Travel time function of the link • Traffic volume function of the link • Translation coefficient between traveling-speed and traffic-volume of a good link • The flow of the link of the detailed network during asymmetric traffic assignment • Travel-cost of link • Traffic volume of the route in a detailed network • The traffic demand between two nodes in a physical network
Route importance	• Traffic performance (Traffic volume) • Emergency value of roads (Access level to service points)
Damage level	• Cost (repair/renew cost model) • Traffic functional affect (Traffic functionality model)

3.1.3. Optimization of Post-Disaster Reconstruction of Transportation Networks

Various authors have developed studies to optimize the prioritization of the reconstruction of transportation networks after a disaster. For example, Orabi et al. *(9)* proposed an optimization model to address two research gaps: (1) the dynamic aspect of the reconstruction; and (2) the overall network performance loss and reconstruction costs. Their model used as an application example the transportation network data of Shelby County, Tennessee. The major shortcoming of their study was not presenting an objective criterion to prioritize projects reconstruction. El-Anwar et al. *(10)* proposed an optimization model considering two prioritization aspects: (a) the starting dates of projects; and (b) the assignment of contractors. Their solution minimized the computational effort of the optimization process. The application of the model used the scenario of a previous study with 7 transportation projects and 3 competing contractors. However, this study did not present an objective criterion. El-Anwar et al. *(11)* introduced an optimization model aiming to reduce the computation effort during the prioritization process. Researchers considered the recovery projects and the assignment of contractors minimizing both the overall duration and cost. Their model was applied using an illustrative example and resulted in a Pareto front solution with optimal global solutions for 17 weight combinations of construction cost and traffic performance. Table 3 shows the prioritization parameters and constraints used in the model.

Table 3. Criteria to prioritize road recovery after a natural disaster depending on total traffic disruptions and total reconstruction costs *(10)*.

Parameters	Constraints
Total traffic disruptions	• Project finish dates
Total reconstruction costs	• Total cost (utopia) • Total traffic disruption

3.1.4. Maintenance Prioritization

Prioritization models are also applied for decision-making of road or infrastructure maintenance. In this context, the solutions are applied without the consideration of a disaster. Orugbo et al. (*12*) proposed a method to prioritize maintenance of category 1 defects on trunk road networks. This nomenclature of road surface defect is used by the United Kingdom (UK). The study considered roads, structures, and maintenance events from a UK trunk road network. Their defects include those that cause a rapid deterioration of the structure and hazards to the road networks and require urgent attention. Moreover, this study also considered the trunk road network sub-assets (e.g., carriageways, graters, and frames, etc.) Table 4 lists their criteria to prioritize maintenance activities.

Table 4. Criteria to prioritize road maintenance *(12)*.

Parameters	Factors
Criticality analysis	• Failure modes • Risk associated with the failure modes • Preventive maintenance strategies
Hierarchy analysis	• Function • Downtime • Utilization • Maintenance requirement • Regulation • Risk

Arif et al. *(13)* proposed a decision-making framework for infrastructure maintenance extending the traditional single criterion of physical condition to other parameters aiming to attain a better application of limited funds. Researchers also did a review of previous existing frameworks and the criteria used in these frameworks. Their framework was applied in a US DOT for a maintenance investment decision-making process. Researchers considered four bridges in a period of 5 years, and after their analysis the best cost/benefit solution was chosen. Table 5 lists the criteria used in this study, and Table 6 lists the source of their criteria from previous studies compiled by the author.

Table 5. Criteria to prioritize infrastructure maintenance *(13)*.

Parameters	Factors	Constraints
Strategic importance	• Alternative routes • Emergency responses route • Defense considerations • Age of infrastructure	• Budget
Infrastructure utilization	• Quantity of travel • Congestion (congested conditions) • Commercial traffic • Freight load capacity	• Budget
Socioeconomic contribution	• Accessibility • Affordability • Traffic safety • Quality of travel	• Budget
Physical condition	• Deck condition • Superstructure condition • Substructure condition • Channel condition • Culvert condition	• Budget

Table 6. Review of previous frameworks to prioritize infrastructure maintenance *(13)*.

Author	Parameters	Constraints
Wang and Liu (*13)*	• Physical condition	
Hsieh and Liu (*14)*	• Monetary return • Resource maximization • Delay minimization	• Budget • Personnel
Gharaibeh, Darter and Uzarski (*15)*	• Physical condition • Crashes rates	• Budget
Fwa, Chan and Hoque (*16)*	• Physical condition	• Budget
Sobanjo (*17)*	• Physical condition	
Sadek, Kvasnak and Segale (*18)*	• Physical condition	• Budget • Condition
Hastak et al. (*19)*	• Socioeconomic factors • Management considerations	• Budget
ASME (*20)*	• Economic • Environmental • Societal factors	• Budget

3.1.5. Post-Earthquake Restoration Process with Repair Prioritization of Highway Network System

Nifuku *(22)* proposed a repair prioritization algorithm for road segments that targets emergency activities, logistic, and economy recovery. The prioritization parameters and constraints considered in this model are shown in Table 7. The model was applied using a potential scenario earthquake. Their results track the time and the number of bridges that are rehabilitated; collapsed bridges that need to be reconstructed; and damaged bridges that still need to be rehabilitated. The results include, but are not limited to: (1) the relationship between physical recovery and performance recovery; (2) how long it takes for a full restoration of a highway network system performance degradation; (3) how long it takes to reverse the opportunity loss and the losses of driver's delays; and (4) the social economic and time losses.

Table 7. Criteria to prioritize post-earthquake highway network system prioritization *(22)*.

Parameters	Factors	Constraints
The difficulty of repair work	• Bridge span • The degree of bridge skew • Soil condition at the site • Bridge damage ratio	• Number of regional labors for bridge construction
Importance of damage link	• Link volume (CPU) calculated on the intact traffic status	
The urgency of repair work	• Bridge repair mean time	
Cost for bridge repair	• Bridge damage ratio Bridge deck area	

3.1.6. Cross-Modal Project Prioritization

In 2014, the North Carolina DOT (NCDOT) conducted a peer exchange study (*23*) to gather experience from other transportation organizations. The NCDOT wanted to inform their cross-modal project prioritization due to the challenges in applying the Strategic Transportation Investment (STI) legislation. Their study sought to get examples, suggestions, best practices, and difficulties in comparing and normalizing prioritization scores across different modes. Their study resulted in a list of possible criteria to be used by the NCDOT and other transportation agencies. Table 8 summarizes the criteria used by NCDOT and other transportation agencies.

Table 8. Criteria to prioritize cross-modal investments (*23*).

Transportation Agency	Parameters
NCDOT	• Benefit-cost • Economic competitiveness • Lane width • Shoulder width • Congestion • Freight • Pavement condition • Safety • Accessibility/connectivity • Multimodality • Non-highway criteria (minimum of 4 quantitative criteria per mode)
Delaware Department of Transportation (DelDOT)	• Safety • System operating effectiveness • System preservation • Multimodal mobility/flexibility/accessibility • Environmental impact/stewardship • Revenue generation and economic development • Impact on the public/social disruption/environmental justice
Genesee Transportation Council (GTC)	• Safety • Mobility and accessibility • Community and economic development • System continuity and optimization • Environment • Fiscal responsibility • Mode-specific criteria (up to 30 points out of 130)
Metropolitan Transportation Council (MTC)	• Climate protection • Adequate housing • Particulate matter • Collisions • Active transportation • Open space • Equitable access • Economic vitality • Non-auto mode share/VMT • State of good repair • Benefit-cost assessment
Oregon Department of Transportation (ODOT)	• Economic development • Social benefits • Environmental stewardship • Safety • Project readiness • Leverage
Virginia Department of Transportation (VDOT)	• VDOT is developing weighing strategies and potential performance measures for the Commonwealth Transportation Board • According to House Bill 2, VDOT's prioritization must weight factors such as congestion mitigation, economic development, accessibility, safety, and environmental quality. • In areas with populations over 200,000, there will be additional composite transportation and land use factor.

3.1.7. Rail Projects Prioritization

The Texas DOT (TxDOT) developed a process to prioritize rail projects. Their objective was to attend the rail system needs as well as the strategic goals considering all transportation modes (cross-modal) *(24)*. The research team originally proposed 11 criteria organized in 3 different categories that the TxDOT should consider during the evaluation of rail projects. In this study, the weight of each criterion was clearly presented, with an emphasis on the "transportation" category. Table 9 lists both the original and the adopted criteria to prioritize rail projects.

Table 9. Criteria to prioritize rail investments in Texas *(24)*.

Criteria source	Parameters	Factors	Weight
Originally proposed	Sustainability	1. Cost Effectiveness 2. Economic Impact 3. Environmental/Social Justice 4. Safety and Security 5. Asset Preservation	-
	Transportation	6. Connectivity 7. Mobility 8. System Capacity	-
	Implementation	9. Project Readiness 10. Partnerships 11. Innovation	-
Texas rail plan adopted	Sustainability	Economic Impact	10
		Environmental/Social Impact	10
	Transportation	Asset Preservation	15
		Safety and Security	10
		Connectivity	10
		Congestion Relief	10
		System Capacity	15
	Implementation	Cost Effectiveness	5
		Project Development	5
		Partnerships	5
		Innovation	5

3.1.8. Bridge Retrofit Prioritization Critical for Effective Pre-Disaster Risk Mitigation of Road Transportation Networks

Zhang and Wang (*25*) proposed a resilience-based approach model for pre-disaster situations to mitigate the damages of road transportation networks after disasters. The goal of the model is to assess the performance metric of the system network components and to apply a ranking solution to prioritize bridge retrofit projects while minimizing the impacts of a disaster. The final prioritization solution is a trade-off between the network performance and the cost of the alternative. Each alternative includes a different number of bridges selected for retrofit and different bridges. The solution was applied using a hypothetical community road system exposed to an earthquake, with 37 links representing the roads, 30 nodes representing the road intersections and economic hubs, and one bridge per road. Table 10 presents the components of this solution.

Table 10. Criteria to prioritize bridge retrofit in a pre-disaster situation *(25)*.

Parameters	Factors
Reliability	• Relative importance of the node being connected in the context of community post-disaster emergency response • Average daily traffic (ADT) of the independent pathway • Length of the independent pathway
Cost	

3.1.9. Critical Success Factors for Post-Disaster Infrastructure Recovery

Liu et al. *(26)* studied the Critical Success Factors (CSFs) influencing the decision-making process of post-disaster infrastructure recovery by analyzing the case of the Canterbury, NZ earthquake recovery. The study identified 6 main CSFs that can lead to a successful post-disaster recovery process. Researchers aimed to fill the gap between the managerial contexts and the technical aspects involved during prioritization. One of the CSFs identified was the determination of rebuild project prioritization methodologies. The model presented considered primarily 6 prioritization factors and a posterior ranking adjustment considering other factors and priorities. Table 11 presents the prioritization factors.

Table 11. Criteria to prioritize bridge retrofit in a pre-disaster situation *(25)*.

Parameters	Factors
Project Prioritization	• Asset condition score • Asset criticality score • Post-EQ loss of service score • Asset maintenance cost score
Catchment Prioritization	• Hydraulic dependency • Geographical proximity dependency

3.1.10. Bridge Recovery After a Natural Disaster

Karlaftis et al. *(27)* proposed a new methodology to fund allocation of transportation network recovery after disasters. Their methodology only focused on bridges and considered two criteria and a constraint (Table). The model was applied to a hypothetical disaster affecting the Athens (Greece) area and a set of 400 existing bridges. Two earthquakes scenarios were tested, one where 15% of the bridges were damaged and the other where 35% of bridges were damaged. The results showed how many bridges can be repaired up to the operating level and how many can be repaired up to the pre-disaster condition, considering the limited budget. Then, the solution showed the budget estimation for repairing the rest of the bridge network.

Table 12. Criteria for fund allocation for bridge recovery after a disaster *(27)*.

Parameters	Constraints
Bridge - level of importance Bridge - condition level	• Budget

3.1.11. Bridge Network Maintenance

Another example of the importance of decision prioritization after disasters is in the area of bridge repair prioritization after disasters. Liu and Frangopol *(28)* developed a framework to assist bridge maintenance fund allocation considering the bridges not only as single elements but rather part of a transportation network. The framework considered the bridge structural reliability, the transportation network performance, and the life-cycle cost. Table 13 presents the criteria used by the authors in this study and from a previous study. The proposed framework was applied to a bridge network in Colorado which includes 13 (thirteen) different types of bridges and 6 (six) links. A total of 73 optimized solutions were obtained and three different Pareto-front analysis were produced where the decision-maker can choose the preferable alternative among all the trade-offs.

Table 13. Bridge maintenance fund allocation criteria *(28)*.

Author	Parameters	Factors	Constraints
Liu and Frangopol (*27)*	Performance deterioration patterns of individual bridges		Reduce PV of life-cycle network maintenance cost
	Network flow patterns of individual network modes		Reduce PV of life-cycle network failure cost
	Effects of different maintenance types on bridge performances	• Resin injection • Slab thickness increasing • Steel plate attaching Replacement	Reduce PV of life-cycle network user cost
Liu and Frangopol (*28)*	Network connectivity		
	Lifetime maintenance cost		

3.1.12. Resource Allocation of Available Funding to Transportation Programs of Work

The allocation of funds to transportation programs of work is important to understand the prioritization of projects in the event of disasters. Numerous studies have gathered how resources need to be allocated in transportation programs. Duncan and Schroeckenthaler *(30)* conducted an extensive study called NCHRP Synthesis 510. Their study investigated how U.S. transportation agencies allocate resources to transportation programs. The study included a literature review, an online survey where 42 of the 50 USDOTs responded, and four cases examples. Although this study did not provide the objective criteria used by the DOTs to allocate funds, their research produced seven aspects considered during their allocation strategy (Table 14). Additionally, their study provided some points for future research towards the prioritization of resources.

Table 14. Aspects considered by transportation agencies during fund allocation *(30)*.

Aspects
Preservation versus Improvement balance
Modal balance
Geographic balance
Accountability (transparency versus complexity)
Top-down versus bottom-up
Agency discretion/flexibility versus policy/model-driven consistency
Objectivity versus subjectivity

3.1.13. Optimization of Bridge Retrofit and Post-Event Repair Selection to Enhance Sustainability

Tapia and Padgett *(31)* proposed a framework to identify an optimal combination of bridge retrofit and repair after earthquakes. The objective of their model is to pre-assess the bridges performance and the need for retrofit or repair to minimize the damage after a disaster. The model integrates criteria of public safety and criteria associated with three sustainability dimensions: (1) environmental, (2) economic, and (3) social. Table 15 shows the criteria adopted in this model.

Table 15. Criteria to prioritize bridge retrofit and repair to enhance sustainability *(31)*.

Parameters	**Factors**	**Constraints**
Bridge configuration options		Public safety
Total service life of the structure		
Bridge components		
Possible repair actions		
Damage level		
Embodied energy (EE)	• Retrofit construction • Operation • Maintenance • Hazard exposure • Demolition	
Carbon dioxide (CO2) emissions	• Retrofit construction • Operation • Maintenance • Hazard exposure • Demolition	
Monetary cost (MC)	• Retrofit construction • Operation • Maintenance • Hazard exposure • Demolition	
Waste (W)	• Retrofit construction • Operation • Maintenance • Hazard exposure • Demolition	
Downtime (D)	• Retrofit construction • Operation • Maintenance • Hazard exposure • Demolition	
Fatalities (F)	• Retrofit construction • Operation • Maintenance • Hazard exposure • Demolition	

3.1.14. Statewide Transportation Improvement Program

The Texas Department of Transportation (TxDOT) produced three documents planning of transportation infrastructure projects. This section describes each of them individually.

The first document is the TxDOT Statewide Long-Range Transportation Plan 2035 (SLRTP 2035) *(31)*, a 24-year planning for the overall transportation system. This plan incorporates a project evaluation methodology that expands the Texas Highway Trunk System with additional criteria to prioritize highway trunk system corridors. Table 16 presents the parameters and the and the weights selected for optimization.

Table 16. TxDOT SLRTP 2035 criteria for prioritization of highway trunk system corridors *(32)*.

Parameters	Weights
Coincident Needs. Segment Length (Miles)	20%
Passenger Traffic (2008 AADT)	15%
Truck Traffic (2008 AADT)	15%
Remaining Needs Segment Length (Miles)	15%
Population (Est. 2008 MPO)	10%
Capacity Needs	10%
Military Connections	5%
Hurricane Evacuation Routes	5%
Major Ports of Entry	5%

In 2016, the TxDOT released the 2017-2020 STIP *(33)* with a 4-year program of transportation infrastructure improvement. This document contains the criteria used by some districts to prioritize rural transportation projects. Table 17 shows the criteria and factors used for each district.

The last document was a UTP published by the TxDOT in 2018. This UTP *(34)* contains a 10-year planning and programming for transportation, including public transportation, aviation, rail, and state and coastal waterways. This project and portfolio evaluation performance assessment considered a set of criteria linked to key performance objectives.

Table 18 shows the evaluation criteria using in the TxDOT UTP 2018.

In summary, and according to the three above-mentioned prioritization factors and institutional barriers from both literature and current state DOTs practice, a survey questionnaire (Appendix A) was developed for data collection in the next step.

Table 17. Texas Transportation Improvement Program for Rural areas *(33)*.

District	**Parameters**	**Factors**	**Constraints**
General (TxDOT STIP 2017-2020)	Pavement condition scores		
	Daily traffic		
	Percent of truck traffic		
Beaumont District Rural TIP Public Involvement Process	Roadway preventive maintenance projects	• Pavement management system data • Distress and repair history • Historical repair costs • Local material and geotechnical factors • Age • Visual evaluation surveys	Funding
	Bridge projects	• Bridge sufficiency ratings • Ranking criteria	
	Safety-related projects	• Number of Crashes (last 3 yrs) potential to reduce future crashes in the same location	
	Mobility projects	• Congestion • Connectivity	
Childress District Rural TIP Public Involvement Process	Crash Data ADT Pavement scores Maintenance expenditures Available funding/estimates		
Dallas District Procedures for Rural TIP Consultation	Roadway maintenance projects	PMIS (pavement evaluation) scores	
	Bridge projects	• Bridge sufficiency ratings • Ranking criteria	
	Mobility projects	Available funding and/or budget	
Lubbock District Procedures for TIP Consultation on Rural Projects	PMIS scores Other critical criteria		
Waco District Consultation Process	Roadway maintenance projects	PMIS (pavement evaluation) scores	
	Bridge projects	• Bridge sufficiency ratings • Ranking criteria	
	Mobility projects	• Available funding • Need • Local support	

Table 18. Project and portfolio evaluation performance assessment criteria *(34)*.

Portfolio Objective	Performance Metric Criteria	Metric Sub-Criteria
Safety	Crash count	• Fatal and incapacitating injury crashes • Total crashes
	Crash rate	• Fatal and incapacitating injury crashes • Total injury crash rate
	Safety Project Classification	
	Hurricane Evacuation Route	
Preservation	Bridge condition	• Structurally deficient deck area addressed • Good deck area maintained (by sufficiency rating)
	Pavement condition	• Poor or worse lane miles addressed (by Ride Score) • Good or better lane miles addressed (by Ride Score) • Poor or worse lane miles addressed (by Distress Score) • Good or better lane miles addressed (by Distress Score)
Congestion Reduction	Lane miles of current congestion addressed	
	Lane miles of future congestion addressed	
	Intermodal connector	
	Lane miles of new connectivity	
Enhance Connectivity	Lane miles of current congestion addressed	
	Lane miles of future congestion addressed	
	Trunk system route	
	Intermodal connector	
	Lane miles of new connectivity	
Effects on Economic Development	Economic importance	• National Highway System (NHS) route • National Highway Freight network (NHFN)
	System usage	• Base ADT • Base percent trucks • Energy sector route
Effects on the Environment		• Category 5 (Congestion Mitigation and Air Quality) projects • Hazardous paint removal and landscape and scenic enhancement projects • Environmental work (e.g., wetland mitigation)

3.2. Applied Methods for Prioritization for Transportation Construction Projects

This section investigates strategies for post-disaster accelerated construction, and identify key methods used in decision support systems for prioritization from the academic community. This section reviews articles from transportation and civil engineering journals, and technical reports from transportation agencies and similar organizations. Additionally, newspapers and online articles were used to identify the frequency and severity at which different transportation infrastructure components are typically affected by hurricanes and flooding events. The various methods have been grouped in academic areas. Even when the application of this prioritization is not intended for field decisions in the environments of emergencies, the summary of past efforts from mathematical approaches is gathered in order to sort current efforts as a literature review resource for the community in the area of post-disaster accelerated prioritization optimization. This context will be used to inform the model along with the expert feedback in order to better combine both past works in academia with industry input.

3.2.1. Genetic Algorithm

Zhang and Wang *(25)* presented a resilience-based performance measurement based on graph theory to quantify road performance capacity after a disaster. This metric included weighting mechanism and integrates parameters such as network topology and redundancy level. Researchers developed a multi-objective optimization approach to prioritize reconstruction of bridge projects which are critical in mitigating pre-disaster risk for road networks. Additionally, Tapia and Padgett *(30)* developed a multi-objective Genetic Algorithm framework. Their model minimized not only cost regarding the lifetime of infrastructure but also costs related to society and the environment. Similarly, Orabi et al. *(9)* developed an equilibrium algorithm to evaluate the functionality of transportation networks after a disaster. Their research planned infrastructure recovery using Multi-objective Genetic Algorithm. As there was a limitation in the availability of resources in the reconstruction process, researchers considered the optimized allocation of resources to projects. In addition, the cost of each plan was calculated.

Liu and Frangpool *(28)* designed a multi-objective genetic algorithm to plan a bridge repair practice. Researchers determined the impact of the failure of a bridge on the whole roadway network system. Expenses of bridge failure, recovery, and user were considered as objective functions. Due to the inefficiency of considering a single life cost provided by adding the cost of all origins, researchers integrated analysis of network, evaluation of reliability for time-dependent infrastructures which support enough safety of bridges as well as analysis life-cycle cost in the proposed model.

Chen and Tzeng *(7)* presented an optimal fuzzy multi-objective model to assist with restoration decision for a post-quake road network as a reconstruction schedule by utilizing the concept of network restoration problem (NRP) and genetic algorithm (GA). The authors also addressed an asymmetric traffic assignment technique as a measurement tool for the effectiveness of this restoration schedule. In their work, the authors developed and applied a modified GA technique in order to overcome the sophistication of the model, which is a combinatorial NP-hard complexity optimization problem.

3.2.2. Mixed Integer Linear Programming

El-Anwar et al. *(11)* proposed a model to optimize plans of retrofitting damaged transportation networks after a disaster using Mixed Integer Linear Programming. As the inherence of such problems is non-linear, researchers redesigned decision variables and objective functions to overcome challenges working with logical operators. The presented methodology was functional for assignment of contractors. To minimize the computational time, researchers used a set of strategies: (i) producing a primary prioritization plan; (ii) creating a local optimized recovery plan; and (iii) eliminating suboptimal solutions for prioritization. Therefore, it was not required to perform traffic analysis for all feasible reconstruction plans as well as search space was reduced considerably.

El-Anwar et al. *(10)* addressed an optimization-based solution of reconstruction plans for damaged transportation networks in the post-disaster period. Their paper considered efficient and optimized reconstruction plans such as the optimal start date of the projects, contractor's plans, limited resources, etc., while optimizing total computational/functional costs. Their work used four traffic decomposition techniques inspired by goal programming and linear-integer programming, in order to reduce the computational complexity of the optimization problem without losing the accuracy of the proposed reconstruction plans solutions.

3.2.3. Analytic Hierarchy Process

Orugbo et al. *(12)* developed a model using the integration of Analytical Hierarchy Process (AHP) and Reliability Centered Maintenance to produce a prioritization plan of roadways recovery. The reliability logic and its associated risk numbers were used to categorize failures of roads into 4 groups and to reclassify them. AHP was also applied to (i) analyze decision-making criteria, and (ii) break down the road network prioritization plan into easier levels and deal with linguistic variables.

Nifuko *(22)* introduced a probabilistic solution to deal with the process of recovering highway networks after the earthquake. Their research used four criteria as decision making parameters to plan the repairing prioritization. AHP was applied to (i) calculate numeric values of factors weights and (ii) order bridge restoration.

Oh et al. *(35)* calculated criticality measurement of infrastructure systems to provide a prioritized list of infrastructures which required attention in case of an emergency. Researchers also incorporated vulnerability and intensity assessment as their two main criteria for the decision support system. In fact, researchers included new aspects such as the impact of critical infrastructure on industries and communities in their decision-making process. Researchers wanted to determine how a disaster influence an individual's social and economic life. To gather information, researchers used site investigation, questionnaire, and interviews and inserted them as input into AHP to find the relative importance of infrastructures. In this research project, the authors of this report followed a survey model to inform the model simulation for prioritization of decisions.

3.2.4. Vikor Method

Zamanifar and Seyedhosseini *(8)* developed a Fuzzy VIKOR technique to deal with a problem related to the ranking of reconstructing roadways after disasters. Using heir VIKOR method researchers provided a rating list as an optimized solution as the weight of stability intervals. Researchers integrated a criterion for the retrofit of roadways after a natural disaster to produce a list for recovery operation action plan. Factors were quantified using fuzzy triangular numbers and both ArcGIS and EMME2 were used for network and traffic analysis.

Opricovic and Tzeng *(36)* developed a multi-objective technique to provide strategies for mitigating societal expenses resulted from disasters. Researchers considered a redistribution of the population inside an affected area. Researchers compared multiple scenarios as sustainable risk-reducing plans using compromise Ranking Method VIKOR. In addition, Linguistic and incomplete information was determined using Fuzzy methods.

3.2.5. Network Analysis

Loggins and Wallace *(37)* developed two algorithms to anticipate and analyze the effect of natural hazards on infrastructures. Researchers used a Monte Carlo Simulation and statistical methods to measure damages resulted from hurricanes. Integer programming optimization techniques were applied to find the influence of damage throughout the system. In addition, to visualize data of network, researchers used GIS technology. As researchers have considered three scenarios for damage to all infrastructures, researchers related their proposed model with the decision maker's ability to taking risks.

Basoz and Kiremidjian *(38)* addressed a risk assessment methodology for lifeline systems, more specifically for highway transportation systems subject to earthquakes. Vulnerability and importance assessment of the system's components were the basis for this methodology. The multi-attribute utility theory was employed to influence risk reduction decisions by using factors such as economic/ social factors, as well as the synthesis of engineering. Their work intended to assist the decision making for pre-earthquake mitigation strategies, emergency response planning, and management activities.

3.2.6. Other Methods

Ren et al. *(39)* used Hesitant Fuzzy Set (HFS) to deal with problems regarding emergency decision making. Researchers integrated a negative exponential function with prospect theory in order to consider the psychological behavior of decision-makers and produced a decision matrix. Entropy and energy in thermodynamic have also been applied as a tool to determine decision quality and quantity of values. Finally, researchers used a non-parametric test to validate the presented algorithm.

To consider the risk associated with decision-makers' behavior, Liu et al. *(40)* proposed a technique based on Cumulative Prospect Theory (CPT) to find a solution for emergency response of natural hazards. Researchers used CPT and Choquet integral to determine values of alternatives related to each factor. After calculating values of each response, by aggregating the weight and value of each option a prospect value was proposed for each solution. Finally, researchers ranked plans based on a combination of prospect values and expenses of each action.

Chang *(41)* used life cycle cost analysis to assess expenses of disaster reducing metrics for infrastructure system. The proposed model includes societal impacts as well as changes like the deterioration of infrastructures. It considers the benefits of all individuals in the investigated region instead of focusing on advantages only for utility agencies. Due to applying cross-sectional data rather than time-series data, their model had limitations regarding consideration of increasing repair cost as infrastructure ages.

3.3. Emergency Decision Making (DEM) for Natural Disasters

Moving toward rapid progress in the 21st century and essential needs for fast response to disasters, oblige decision-makers to look at emergency action as a strategic milestone after natural disasters. Providing a crisis management framework to reduce losses after disasters is a prerequisite for emergency response. Some of the studies in this area are summarized below.

Herrera et al. *(42)* used risk and resilience analysis framework presented by "American Society of Mechanical Engineers Innovative Technology Institute" to quantify the impact of threats to highway assets as well as the life-cycle cost of projects and their performance. This framework has also been adopted by the Colorado Department of Transportation to support requests for a fast response after the 2013 flood. According to their framework, numerical values were calculated for risk and resilience assessments based on threat, vulnerability, and consequence to allow decision-makers to choose the best plan for management and prioritization of critical assets. However, the framework is much dependent on data provided by agencies and their way of data collecting.

Zhou et al. *(43)* presented an overview of the Emergency Decision Making (EDM) theory and natural disasters. This work finds the basis for EDM to be on methods of mathematical modeling, situational evolution, knowledge management as well as a group decision. In addition, two emergency decision support systems are employed in the light of GIS and Agent, respectively. In this study, some of the current challenges in EDM are presented: (i) challenges raised by basic characteristics of EDM for natural disasters; (ii) challenges caused by limitation methods of EDM for natural disasters; and (iii) challenges related to development and application of decision support systems.

Liet et al. *(44)* addressed the decision-making process for reconstruction after an earthquake that took place in L'Aquila, Italy in April 2009. The research was done through several interviews with local and national leaders to characterize their views and understanding of the response from the government to the post-disaster plans and decision makings. This case study finds that the emergency response from the department of civic protection was satisfying. However, some of the answers suggested that the funding and priorities for permanent rebuilding were not allocated properly. Also, it showed that local leaders commented about the limited public involvement during post-earthquake recovery periods. The study also specifies the importance of authority and resource coordination among local and national agencies.

Altay and Green *(45)* presented a survey on Disaster Operation Management (DOM) to address the current trend and problems that have not been investigated and need to be taken into consideration. This survey paper oversees the future research trend of DOM in several categories such as: multi-agency research, methods, technology, DOM stages, business continuity, infrastructure design, and management engineering. It addresses the issues and difficulties in operation research regarding system performance which are not optimal. In this study, the main important attributes of the disaster emergency response are uncertainty in the problem, rapid and uncontrollable change in environment, lack of reliable information, little time, as well as the problem of critical disaster response decision.

Kozin and Zhou *(46)* applied dynamic programming to provide a procedure for emergency reconstruction of lifelines after an earthquake. There is a large number of infrastructures requiring restoration after disasters, but the amount of resources is limited. Researchers used discrete-state, discrete-time Markov process to prioritize reconstruction of lifelines with a critical function to mitigate damage caused by natural disaster. In this study, geographical and structural characteristics of the lifeline are considered as two main features for decision making. In addition, researchers compared the economic return from different restoration alternatives.

3.4. Identification of Institutional Barriers

The process to define a prioritization system to infrastructure projects after a disaster and its implementation can face many barriers. Along with the criteria to prioritize projects after a disaster, some studies also reported barriers during such process. Table 19 lists the barriers found in the literature grouped in different sources and listed as items.

Table 19. Institutional barriers from the literature.

Author	Institutional Barriers
Hallegatte, Rentschler and Walsh *(47)*	• Clear allocation of responsibility in the recovery period • Access to practical knowledge and information • Strong and inclusive financial protection provided by a combination of disaster-response social safety nets, insurance mechanisms, and access to borrowing to finance the reconstruction
Texas Department of Transportation (*34*)	• Materials availability and delivery • Equipment capabilities and limitations • Quality control/quality assurance (QC/QA) procedures • Workforce availability • Economic incentives • Public information • Safety considerations • Right-of-Way problems • Environmental permitting • Historic preservation and archaeology-related project impacts • Use of Alternative Contracting Methods (ACM) to deliver projects faster
Duncan and Schroeckenthaler *(29)*	• Preservation versus improvement balance • Modal balance • Geographic balance • Accountability (transparency versus complexity) • Top-down versus bottom-up • Agency discretion/flexibility versus policy/model-driven consistency • Objectivity versus subjectivity
Liu, Scheepbouwer and Giovinazzi (*26)*	• Establishment of a single point (recovery vehicle) responsible to organize the recovery efforts • Clear definition of roles and responsibilities of the parties involved • Pre-establishment of a funding plan for post-disaster infrastructure recovery • Settlement of insurance beforehand • Effective communication with local community • Selection of the rebuild driver infrastructure asset • Integrated data collection and management mechanism
Sharkey et al. *(48)*	• Coordination between infrastructures • Information-sharing between infrastructures • Level of trust between infrastructure managers
Loggins and Wallace (*37)*	• Slow performance of the model's calculations • Effort required to collecting and organizing the data to run models (e.g. HAZUS-MH)
MacAskill and Guthrie (*49)*	• Definition of what resilience means • Marginal utility for increasing resilience needs • Differential investment (a result of differences in marginal utility) • Scope of work • Funding • Balance between socio-political considerations and technical preferences

Author	Institutional Barriers
Middleton *(23)*	• Organizational structure for cross-modal prioritization • Adhering to funding constraints • Modal biases • Tailoring projects to local needs
Liel et al. *(44)*	• Role of bureaucracy • Funding • Lack of attention to economic and business needs as recovery and reconstruction progressed • Lack of a longer-term government plan for reconstruction and rebuilding • Imposition of priori choices to the community; the government arrives with a pre-built package for the reconstruction and the new town • (Lack of) Encouragement of economic investment and employment in the region • Not enough involvement from local construction firms in rebuilding contracts / marginal construction industry's role in reconstruction decision making • Transference of the recovery and reconstruction leadership without a clear operation framework • Influences by politics • Lack of a general involvement during the decision-making process • Doubts about whether long-term reconstruction decisions would truly reduce [seismic] risk - High cost of new technologies and strengthening, new [seismic] codes are difficult to use and unpopular among building industry professionals • Political influence of bribery or criminal activity on reconstruction and recovery activities
Yates and Paquette (5*0)*	• Coordinating communication and actions by multiple functional areas • Encouraging cross-boundary communication between groups with different tasks and roles
Schexnayder et al. *(51)*	• Standard specifications

3.5. Point of Departure

To describe the challenges and institutional barriers that exist and could be revised to enhance a DOT's ability to effectively prioritize post-disaster accelerated construction strategies, the research team did a quick literature search. Current challenges include:

- Unavailability of contractors having the resources to start immediately;
- Difficult communication in emergency projects;
- Inability to make on-site decisions;
- Decision-making is not performed at the lowest level;
- Lack of flexibility on contract agreements;
- Lack of accommodation of changes in the scope of work;
- Absence of performance measures;
- High number of agencies involved in the decision-making;
- Time lags before damage extent is known; and
- Lack of wireless data and voice communications *(2, 4)*.

Even though the current body of knowledge has investigated accelerated construction and post-disaster project prioritization for transportation infrastructure, the studies do not overlap between accelerated construction, emergency operations, and prioritization of infrastructure projects at a programmatic level for post-disaster recovery. Also, prior studies have not focused on a diverse portfolio of projects and have mostly concentrated on projects with similar characteristics. There is a need for further research and guidance to assist state DOTs in identifying and prioritizing needs for accelerated construction after hazard events.

In summary, section 3 focuses on the literature review of different methods for strategies for prioritizing needs for accelerated construction after hazard events. Including identify prioritization criteria, applied methods for prioritization for transportation construction projects, emergency decision making (DEM) for natural disasters and identification of institutional barriers.

In this study, a multi-criteria model for prioritizing accelerated construction needs after a natural disaster is developed. Researchers evaluate strategies for accelerating construction in a cost-effective manner post-disaster considering identification and quantification and decision criteria for a program of critical transportation infrastructure projects.

4. METHODOLOGY

The methodology of this study included three other stages after the literature review. First, a conceptual model was developed. In the next step, a questionnaire was developed to use for the data collection on criteria weights, important infrastructure assets to accelerate and, acceleration methods as well as institutional barriers. Finally, considering the collected data, the optimization model was developed and tested. The following three sections explain each of the steps of the methodology:

- Section 4.1 describes the mathematical justification of the optimization function.
- Section 4.2 illustrates the special value of this study, which is the use of both literature review and the focused interview as the input to the model in a combined effort to capture both academic and the current owner's prioritization practice. In this context, this report is aligned with the extensive literature review in this topic and the current decisions taken by owners in the environment of emergencies.
- Section 4.3 summarizes the optimization model in a tabular format that gathers the inputs from sections 4.1 and 4.2.

4.1. Conceptual Prioritization Model

The prioritization model was developed with five questions in mind: 1) Why do we need to accelerate the construction projects after a hazard event? 2) How do we define the re-establishment of the condition of the affected place? 3) How do we define the “recovery index”? 4) What are the variables that influence the decision to accelerate a construction project? 5) What is the final objective of the strategy for prioritizing needs for accelerated construction? The proposed structure for the prioritization model is shown in Figure 2. The model was developed considering four main block components: the projects’ prioritization criteria, the accelerated methods available, the projects’ alternatives, and the scheduling of the project alternatives.

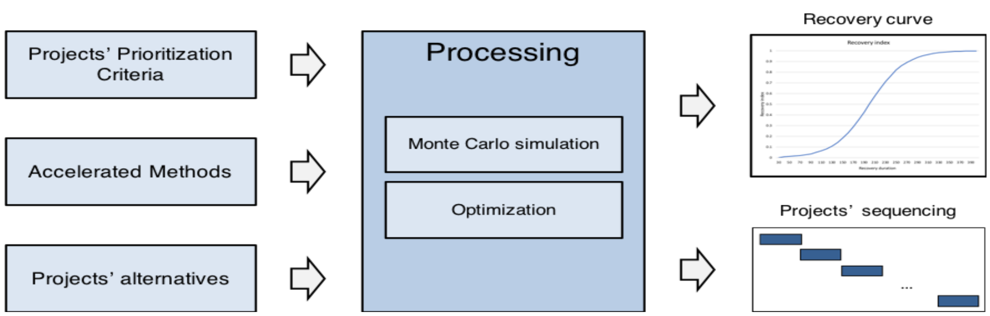

Figure 2. Prioritization model diagram.

4.1.1. Model Inputs

Three of the main block components comprise the inputs of the model: the projects’ prioritization criteria, the accelerated methods, and the projects’ alternatives. Moreover, each of these block components is also defined by a set of variables that are part of the model formulation. The projects’ prioritization criteria component considers the variables of projects, prioritization criterion, criterion weight, criterion value per project, prioritization index, and relative prioritization index. The following indexes are also used: i represents the number of projects and j represents the number of prioritization criteria. The example of the various inputs will outline the specific values for each model in Section 5. However, this section describes the nomenclature and the meaning of each of the sections in detail.

The projects (P_i) of the model represent the potential projects selected to be evaluated as part of the effort to recovering the affected place after the disaster, for example, reconstruction of a bridge that collapsed. The prioritization criteria (C_j) represent the parameters, factors, and subfactors defined to be used to prioritize a project. Each prioritization criterion also has a weight (Wj) that measures the importance of these criteria among the others. Following, for each project and criterion, an importance value (V_{ij}) is established considering the participant's judgment. In this model, an importance value ranges from 1 to 5, where 1 is the lowest importance level and 5 the highest importance level. If a committee is used, the consensus value for each project/criterion needs to be agreed before this phase. However, the consensus process is out of the scope of this paper. Finally, a prioritization index (PI_i) (Equation 1) and a relative prioritization index (RP_i) (Equation 2) are computed. The prioritization index represents the weighted sum of the importance values, and the relative prioritization index represents the relative value of each prioritization value about the sum of all the prioritization values.

$$PI_i = \sum_{\substack{1\leq i \leq N \\ 1<j<M}} (W_j \times V_{ij}) \quad [1]$$

where:
PI_i = Prioritization index;
W_j = Weight of criteria; and
V_{ij} = Importance value for each project and criterion.

$$RP_i = PI_i / \sum_{i=1}^{N} (PI_i) \quad [2]$$

where:
RP_i = Relative prioritization index.

The accelerated methods component represents the potential accelerated methods that the organization considers to be applicable and the preferability of each of these accelerated methods. The accelerated method (A_m) represents each of the methods. Each accelerated method also has a preference value (AP_m). Also, a relative value of each accelerated method preference value (RAP_m) was also developed (Equation 3). This way, different accelerated methods can be considered for the same project, making different alternatives, but one method might be preferred over the other. However, this model does not consider the combination of different accelerated methods into the same project. In this case, the combination of two or more methods needs to be stated as a new accelerated method. The index m is used to represent the number of accelerated methods.

$$RAP_m = AP_m / \sum_{m=1}^{K} (AP_m) \quad [3]$$

where:
RAP_m = Relative value of accelerated method preference; and
AP_m = Value of accelerated method preference.

The last input component of the model is the projects' alternatives list. This list is a combination of the two previous lists. This list contains the combination of the projects and the accelerated methods suitable for the project. This means that not all of the accelerated methods are suitable for all types of project. The model also considers the option of the traditional method without any acceleration. For each combination of project and accelerated method, an estimated project duration (D_{im}) and an estimated project cost (F_{im}) need to be determined. Finally, the final solution is constrained by the available fund to recover the affected area. This means those final solutions where the total recovery cost exceeds the available fund will be eliminated from the possible solutions list.

4.1.2 Model Processing

The model obtains the optimal recovery index of the affected area, with the minimum duration and within the available fund using Monte Carlo simulation with the OptQuest Engine©. The OptQuest Engine© internally combines optimization methods, such as Tabu search, scatter search, integer programming, and neural networks into a single, composite search algorithm. The simulation runs with a maximum number of trials and until the best solution is found. The idea is to randomly schedule the different project alternatives, without project repetition, and use the accelerated method preference as a probabilistic input for the model. This way, if the model selects a project already scheduled, the model will eliminate this option.

4.1.3 Model Outputs

The decision-making process will use four outputs extracted from the simulation results: (i) the accumulated recovery index (ARI), (ii) the total recovery duration (TRD), (iii) the total recovery cost (TRC), and (iv) the accumulated accelerated method preference index (AAMPI). The solutions that do not attend the available fund constraint (B) are eliminated from the list. The AAMPI will work as a soft constraint of the model, meaning that no solution will be discarded regarding the value of the index. The AAMPI will indicate how much of the preferred accelerated methods were used. However, more than one combination of projects can attain the recovery objective. The ARI is expressed by the sum of the relative prioritization index of the projects. The TRD represents the sum of the individual project durations. However, this present model does not consider the potential overlapping of projects. The TRC represents the sum of the individual project costs (Equation 4).

$$TRC = \sum_{\substack{1 \leq i \leq N \\ 1<m<K}} (F_{im}) \qquad [4]$$

where:
TRC = Sum of the individual project costs; and
F_{im} = Estimated project cost.

Therefore, considering the objective to find the optimum combination of projects, while maximizing the ARI and minimizing the TRD, the proposed model can be represented as Equation 6.

$$\text{Max } RI = \sum_{i=0}^{N} (RPi) \qquad [5]$$

$$Min\ TRD = \sum_{\substack{1 \leq i \leq N \\ 1<m<k}} (Dim) \qquad [6]$$

$$\text{Subject to: } \sum_{\substack{1 \leq i \leq N \\ 1<m<K}} Fim \leq B \qquad [7]$$

where:
RI = accumulated recovery index;

TRD = Total recovery duration;
D_{im} = estimated project duration; and
B = Available fund.

4.2. Data Gathering

The purpose of the data gathering was to quantify which assets are important to accelerate after a disaster, the preference of accelerated methods, the importance of prioritization criteria to accelerate projects, and the barriers for the prioritization and implementation of a decision-making model to prioritize which projects to accelerate. After careful examination of the literature review, we found 18 criteria and 69 sub-criteria to be considered as prioritization factors and sub-factors. Researchers also investigated 21 acceleration methods to be discussed in the proposed model. To find weights of alternatives, we prepared a questionnaire (Appendix A). At the first stage, the questionnaire was distributed online and at the second stage, the research team conducted interviews with transportation agency personnel directly involved in program management and disaster/emergency response. The research with people was approved by the UNM IRB (IRB #13618). Researchers have interviewed with 6 experts to get their opinion regarding prioritization criteria and acceleration methods. Collected data are indicated in Appendix B.

The online distribution of the questionnaire used an online survey tool, and it was distributed to 148 professionals from the U.S. Region 6. A distribution list was developed using public information available online and contacts. The population target included professionals from State DOTs, State Departments of Homeland Security & Emergency Management, Metropolitan Arroyo Flood Control Authority, state representations of the U.S. Federal Highway Administration, County administrations, Maintenance Departments, and FEMA. The potential participants received an invitation email to participate in the research. The questionnaire was available for three weeks and reminders were sent once a week. Only one questionnaire was completed online. Therefore, the research team decided to change the approach to do focused interviews. This report focuses on using the experience of the surveyed owners to better inform the prioritization recommendations from the academic literature review, in order to use the past exposure of owners to the emergency scenarios. The value of the past emergencies was taken into account to better capture the impact of experience in this study.

The interviews used the same questionnaire available online and the target were professional from private railroad companies, New Mexico Department of Transportation (NMDOT), and a County in NM. The participants were individually contacted by emails and a phone interview estimated in 20 minutes was scheduled. The interviews occurred in 2018 and a total of 6 interviews were conducted. During the first interview, the research team realized that go through each of the prioritization sub-criteria would make the interview last too long. Therefore, the research team made the decision to quantify only the main criteria items (question 6). Demographic information of participants is represented in Figure 3. Researchers have collected information of participants based on four categories: Their state of working, years of experience, role, and agency. Some of the participants work in multiple states, so their information has been represented in all states that they are working in. In addition, dividing participants based on agency, include “other” section that participants who are placed in this part are from The Association of American Railroads, Railroad industry and, Railroad engineering Consultancy agency.

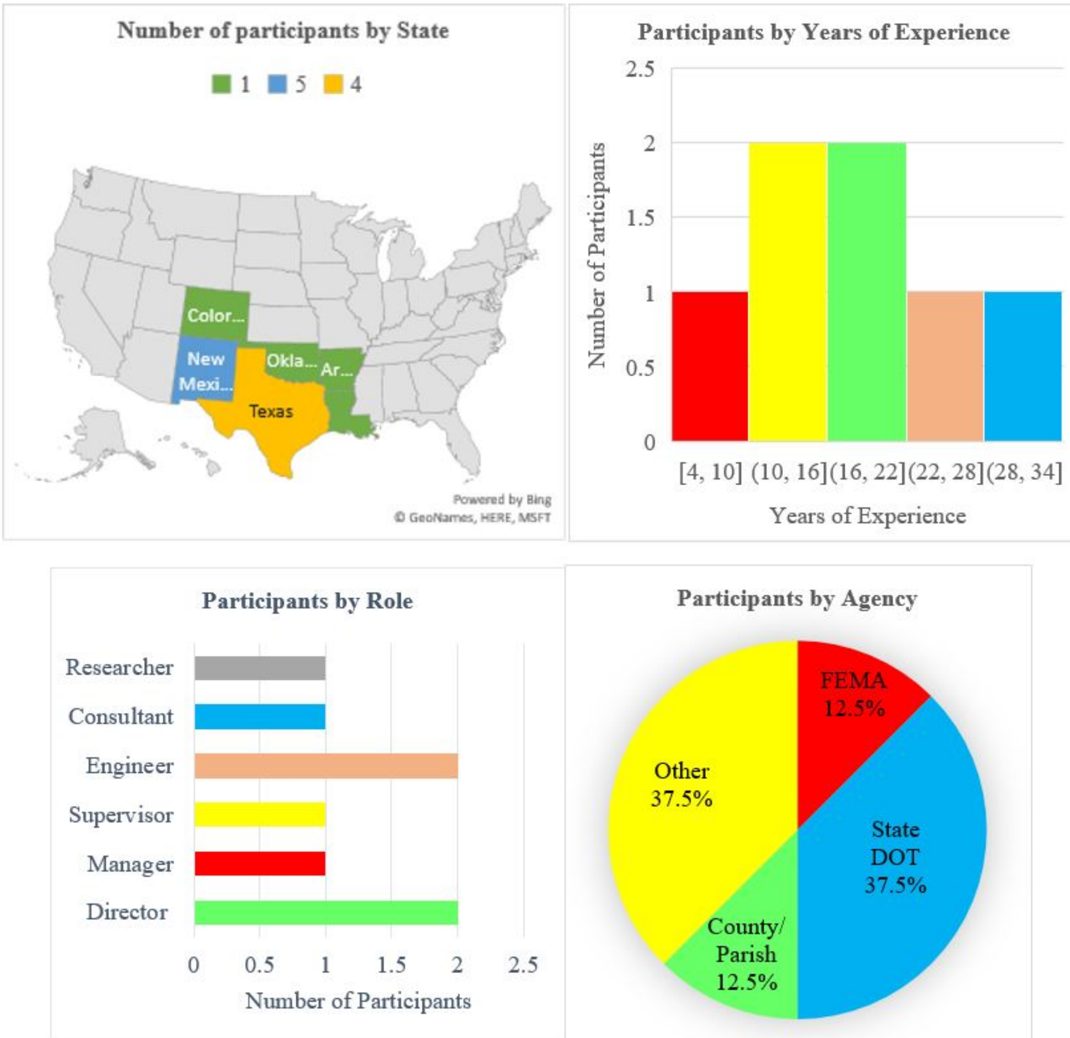

Figure 3. Demographic information of data collection participants.

4.3. Optimization Model

The goal of the optimization model is to find the optimum sequence of projects simultaneously considering accelerated method alternatives. The outcome of this section is to determine the ranking of the project for reconstruction after a natural disaster, in addition to the best acceleration methods that fit this project. It should be noted that we have considered "no acceleration" method as an alternative for project reconstruction. According to that, it is not required to reconstruct project with the accelerated condition and project building can be performed with normal methods without considering critical status.

The model was developed using commercial software that includes an optimization function that combines Monte Carlo simulation and the OptQuest Engine. It would minimize the total duration of the project, subjected to four constraints as follow: (i) maximum value of investment less than available budget; (ii) a cumulative reestablishment index higher than 0.8; (iii) acceleration preference index higher than 0.5 and (iv) uniqueness of the project (it means, for example, project 1 cannot be considered twice). Maximum value of investment, cumulative reestablishment index and, the uniqueness of the project are set as hard constraints. Therefore, if the solution does not attend these conditions, it is discarded. The acceleration preference would be considered as a soft constraint. If the solution does not meet the condition, it is not ignored, and it only can be used by the decision-maker as an additional parameter to compare solutions.

During the optimization process, the trial solutions are generated using the Monte Carlo simulation and the OptQuest Engine. This optimization method combines Tabu search, scatter search, integer programming, and neural networks into a single, composite search algorithm, and additionally, it was set up to use Latin Hypercube sampling, and to stop at 10,000 trials or when a maximum change is 0.1% during 1,000 trials. This study examined two samples of projects to check the performance of the presented model. Each sample contains five projects that need to be reconstructed after a natural disaster. Some assumptions for these cases studies have been considered. First, the scores of projects related to each factor were assigned randomly. Table 20 and Table 21 show these synthetic data for two considered scenarios.

Table 20. Scenario 1 data.

	Weight	Relative Weight	Project 1	Project 2	Project 3	Project 4	Project 5
Safety	10.00	13.62	3	2	2	2	5
Disruption	8.66	11.81	2	2	1	4	1
Connectivity	8.00	10.90	5	3	3	2	5
Traffic	7.83	10.67	2	5	1	2	3
Asset Damage Cost	7.80	10.62	5	5	3	3	2
Budget	7.80	10.63	3	2	1	1	3
Asset Characteristics	7.40	10.08	5	3	1	4	5
Repair Issue	7.40	10.08	1	4	2	2	3
Social Impact	7.25	9.88	5	3	3	4	3
Asset Condition	7.20	9.88	1	4	4	4	5
Socioeconomic	7.20	9.88	3	1	3	5	2
Sustainability	6.75	9.19	1	4	3	3	2
Construction	6.60	8.99	4	5	3	2	5
Economic Impact	6.60	8.99	4	3	1	3	2
Environmental Impact	6.50	8.85	2	5	2	2	1
Vulnerability	6.50	8.85	3	1	1	5	2
Regulation	6.00	8.17	1	2	2	4	5
Political Impact	4.25	5.79	2	5	3	2	5
Prioritization index			**381.40**	**416.70**	**276.95**	**386.98**	**422.97**
Relative Prioritization Index			**0.202**	**0.221**	**0.147**	**0.205**	**0.224**

This study examined two samples of projects to check the performance of the presented model. Each sample contains five projects that need to be reconstructed after a natural disaster. Some assumptions for these cases studies have been considered. First, the scores of projects related to each factor were assigned randomly. Table 20 and Table 21 show these synthetic data for two considered scenarios. Second, since the rank of projects and accelerated method for each specific project should simultaneously be optimized, we randomly selected 25 alternatives of the combination of project and acceleration method. In addition, “no acceleration” method was compared with the selected acceleration method for each specific project. Third, Duration and cost of each project were assigned randomly. So, researchers are not real data and forth, the available total budget for reconstruction projects after the disaster was estimated to be $50,000,000.00. Thus, each scenario meets the value of investment constraint if the total cost of reconstruction projects is less than 50 million dollars.

Table 21. Scenario 2 data.

	Weight	**Relative Weight**	**Project 1**	**Project 2**	**Project 3**	**Project 4**	**Project 5**
Safety	10.00	13.62	2	5	1	5	4
Disruption	8.67	11.81	5	3	3	5	1
Connectivity	8.00	10.90	1	1	2	5	4
Traffic	7.83	10.67	3	3	1	5	1
Asset Damage Cost	7.80	10.63	1	2	4	3	4
Budget	7.80	10.63	1	3	5	3	5
Asset Characteristics	7.40	10.08	1	1	2	3	2
Repair Issue	7.40	10.08	5	1	2	1	5
Social Impact	7.25	9.88	5	4	2	1	4
Asset Condition	7.20	9.81	4	1	2	3	1
Socioeconomic	7.20	9.81	3	3	4	1	4
Sustainability	6.75	9.19	2	4	5	4	3
Construction	6.60	8.99	4	1	2	3	1
Economic Impact	6.60	8.99	3	4	2	4	1
Environmental Impact	6.50	8.85	2	1	1	2	1
Vulnerability	6.50	8.85	4	2	3	4	2
Regulation	6.00	8.17	5	4	1	1	3
Political Impact	4.25	5.79	1	2	5	3	4
Prioritization index			**374.43**	**331.10**	**330.733**	**415.90**	**363.45**
Relative Prioritization Index			**0.206**	**0.182**	**0.182**	**0.229**	**0.200**

5. ANALYSIS AND FINDINGS

The analysis shows the results of the importance weight for the prioritization criteria and acceleration methods. For each scenario/run, first the results of the best solution are presented, then the sub-optimum alternatives are presented. Each solution is represented by the project sequence obtained, the cumulative duration in days of the solution, the cumulative relative reestablishment index, the total duration in days, the total investment necessary, and the acceleration preference index attained with the solution.

5.1. Prioritization Criteria and Accelerate Methods Weight Analysis

Table 22 shows the prioritization criteria and Table 23 shows the acceleration methods suitable for post-disaster remediation. This analysis also determined the most important infrastructure assets to be accelerated after a natural disaster. It shows that in the first position, roads are placed and bridges, highway and drainages, ports and rails are placed in subsequent spots, respectively.

Table 22. Weights of prioritization criteria.

Prioritization Criteria	Weight
Safety	10.0
Disruption	8.7
Connectivity	8.0
Asset Damage Cost	7.8
Traffic	7.8
Budget	7.8
Repair Issue	7.4
Asset Characteristics	7.4
Social Impact	7.2
Socioeconomic	7.2
Asset Condition	7.2
Sustainability	6.7
Construction	6.6
Economic Impact	6.6
Vulnerability	6.5
Environmental Impact	6.5
Regulation	6.0
Political Impact	4.2

The analysis also shows that Safety and Disruption are the most important prioritization criteria, respectively. In addition, Among Acceleration methods, Design-build approaches which provide an opportunity to begin construction before the final design has been completed, obtained the highest rank. We also asked questionnaire respondents to identify additional acceleration methods which can be considered. Spare inventory, pre-qualify on-call contractors and, establishing collaboration among all department and agencies are alternatives which were presented by experts as acceleration methods.

Table 23. Weights of acceleration methods.

Acceleration Method	Weight
Design-build approaches	10.0
Accelerated Bridge Construction	8.7
24/7 calendar	8.5
Packaged multi-primes approach to contracting	8.5
Pre-qualify bidders on the basis of past schedule performance	8.5
Relocation of utilities	8.4
Scheduling fast-track	8.3
A + B bidding	8.3
Work zone traffic control	8.2
Scheduling crashing	8.0
Scheduling activity substitution	8.0
Designate a single individual as PM	8.0
Innovative materials	8.0
Information technology	7.8
Formal partnering	7.5
Public involvement	7.0
Right-of-way (ROW) acquisition	6.4
Full closure instead of partial closure of the roadway	5.8
Linear scheduling method	5.5
Automation equipment/construction technology	5.0
Lane rental approach	3.5

5.2. Identification of Institutional Barriers

In this study, some barriers that can impede or delay the process of implementation and prioritization of accelerated transportation projects were specified through interviews with participants in the survey such as DOT personnel and representatives of emergency management agencies that will likely interact with DOTs during post-disaster accelerated projects including Federal Emergency Management Agency. The barriers that have been investigated for prioritizing procedure are as follows:

1. Flooding, Earthquake, Wildfire, Hurricane, Tornado, Traffic;
2. Government;
3. Resources (personnel, material cost, total cost);
4. No understanding of the complexity of the project;
5. Not having the right people;
6. Time to get the necessary permits;
7. Availability of required materials (LLI);
8. Amount of time to access the location; and
9. The communication barrier that must be overcome first, including communication with the public. Communication between stakeholders is huge as well in order to effectively

and efficiently return affected assets to service. For example, the railroads may need some assistance from public agencies in the form of relaxation of permitting issues (i.e., oversized loads going over highways (typically already in place) and environmental permits).

In addition, barriers which can impede the implementation of accelerated transportation projects are:

1. Flooding, Earthquake, Wildfire, Hurricane, Tornado, Traffic; for example, an aftershock can impede the recovery to normal conditions:
2. Weather;
3. The duration that the construction team should wait until the disaster is over and finally;
4. Planning ahead can significantly assist with responding to disaster damages in a short time. In fact, state, county, and local agencies must be aware of available assets, and there should be agreements in place among all sectors. Additionally, every agency is expected to conform with the Federal Emergency Management Agency (FEMA) Incident Command System model to restore services as quickly and efficiently as possible since the FEMA incident commander will be making most of the decisions needed at the highest levels during the recovery period. Besides, agencies should be in contact with contractors, material vendors, and others to put them on alert, if not mobilize.

In addition, the interviews with private railroad companies and DOTs revealed that private and public entities face different barriers, and they have different perceptions. For example, the accelerated delivery method Design-Build (D-B) is appreciated by the DOT professional, but it is not an approved method in many states. On the other hand, private railroad companies can use D-B without restriction. Another finding was that private railroad companies have more flexibility than public entities to mobilize resources from other sites in case of an emergency.

The institutional barriers were identified through the literature and the data collection in a qualitative way. There were similarities in the barriers identified through the literature review and the data collection. The list below highlights these similarities:

- Resources (material, equipment, workforce);
- Permits;
- Communication;
- Coordination; and
- Funding.

Besides, similarities were also found among the different studies in the literature review:

- Allocation of responsibility;
- Funding;
- Data and information;
- Socio-political aspects; and
- Policies.

The literature review and the data collection revealed that the majority of the institutional barriers associated to a disaster recovery process are related to organizational, political, or procedural issues (e.g., allocation of responsibilities, public information, communication, pre-planning, etc.). These types of barriers can affect or delay the project prioritization process. Among the identified barriers, four types of barriers can directly affect the prioritization of projects after a disaster, such as material availability, equipment availability, workforce availability, and funding. However, if any of these items is not available, the procedure is not to include these projects in the prioritization. The amount of funding available to allocate in the projects was a variable directly considered in the proposed prioritization model. The other identified barriers need to be treated in an ad-hoc way during the whole decision-making process, especially because many of them involve subjective aspects.

5.3. Hypothetical Scenarios Prioritization Results

5.3.1. Scenario 1 Optimization Process

The results for scenario 1 are shown in Table 24, Table 25 and Table 26, and in Figure 4. Optimization process stopped after 1,172 trials, and 575 of them were valid, which means the number of trials where the hard constraints were met. The best solution was found during trial 172 at the time of 0:00:40 and before the best solution, two other sub-optimal solutions were found. The best solution included four projects with acceleration and one project without acceleration. This combination produced a total duration of 1,664 days and a total investment of around $49.5 million. This solution provides approximately 80% of the reestablishment condition of the area affected at the end of the fourth project, or in 1,257 days. The acceleration preference index obtained was 0.29. The two sub-optimum solutions were considered sub-optimum because the total duration was longer than the optimum solution, however, these two solutions had a lower investment, a cumulative relative reestablishment index a little higher than 80% at project four, and a higher acceleration preference index than the best solution.

Table 24. Best solution results for scenario 1.

Project Sequence	**Alternative #: Project/Acceleration Method**	**Cumulative Duration (Days)**	**Cumulative Relative Reestablishment Index**
1	12: Project 3-Crashing	216	0.182
2	2: Project 1-Fast-track	567	0.388
3	18: Project 4-Activity substitution	1,022	0.617
4	8: Project 2-Fast-track	1,257	0.800
5	21: Project 5-No acceleration	1,664	1.000
Total duration (days)	1,664		
Total investment ($)	49,424,022		
Cumulative relative reestablishment (index)	1		
Acceleration preference (index)	0.29		

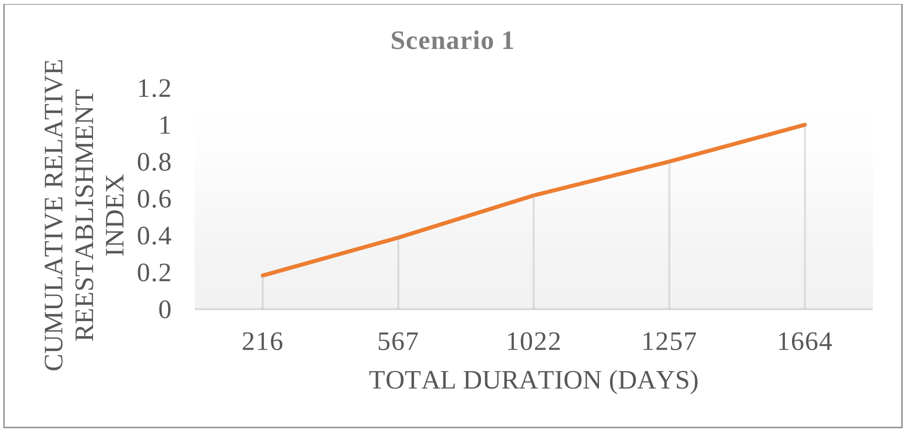

Figure 4. Cumulative relative reestablishment index for scenario 1.

Table 25. Sub-optimum solution (trial 23) results for scenario 1.

Project Sequence	Alternative #: Project/Acceleration Method	Cumulative Duration (Days)	Cumulative Relative Reestablishment Index
1	2: Project 1-Fast-track	351	0.206
2	16: Project 4-No acceleration	900	0.435
3	8: Project 2-Fast-track	1,135	0.618
4	21: Project 5-No acceleration	1,542	0.818
5	11:Project 3-No acceleration	1,907	1.000
Total duration (days)	1,907		
Total investment ($)	27,233,500		
Cumulative relative reestablishment (index)	1		
Acceleration preference (index)	0.378		

Table 26. Sub-optimum solution (trial 61) results for scenario 1.

Project Sequence	Alternative #: Project/Acceleration Method	Cumulative Duration (Days)	Cumulative Relative Reestablishment Index
1	12: Project 3-Crashing	216	0.206
2	2: Project 1-Fast-track	567	0.412
3	16: Project 4-No acceleration	1,116	0.642
4	8: Project 2-Fast-track	1,351	0.824
5	21: Project 5-No acceleration	1,758	1.024
Total duration (days)	1,758		
Total investment ($)	46,889,023		
Cumulative relative reestablishment (index)	1		
Acceleration preference (index)	0.333		

5.3.2. Scenario 2 Optimization Process

The results for scenario 2 are shown in Table 27, Table 28 and Table 29, and in Figure 5. Optimization process stopped after 1,526 trials, and 770 of them were valid, which means the number of trials where the hard constraints were met. The best solution was found during trial 526 at the time of 0:01:14 and before the best solution, two other sub-optimal solutions were found.

The best solution included four projects with acceleration and one project without acceleration. This combination produced a total duration of 1,695 days and a total investment of around $48.3 million. This solution provides approximately 80% of the reestablishment condition of the area affected at the end of the fourth project, or in 1288 days. The acceleration preference index obtained was 0.33. The two sub-optimum solutions were considered sub-optimum because the total duration was longer than the optimum solution, however, these two solutions had a lower investment, a cumulative relative reestablishment index a little higher than 80% at project four, and a higher acceleration preference index than the best solution.

Table 27. Best solution results for scenario 2.

Project Sequence	Alternative # : Project/Acceleration Method	Cumulative Duration (Days)	Cumulative Relative Reestablishment Index
1	4: Project 1-ABC	288	0.206
2	8: Project 2-Fast-track	523	0.389
3	12: Project 3-Crashing	739	0.571
4	16: Project 4-No acceleration	1,288	0.800
5	21: Project 5-No acceleration	1,695	1.000
Total duration (days)	1,695		
Total investment ($)	48,319,123		
Cumulative relative reestablishment (index)	1		
Acceleration preference (index)	0.331		

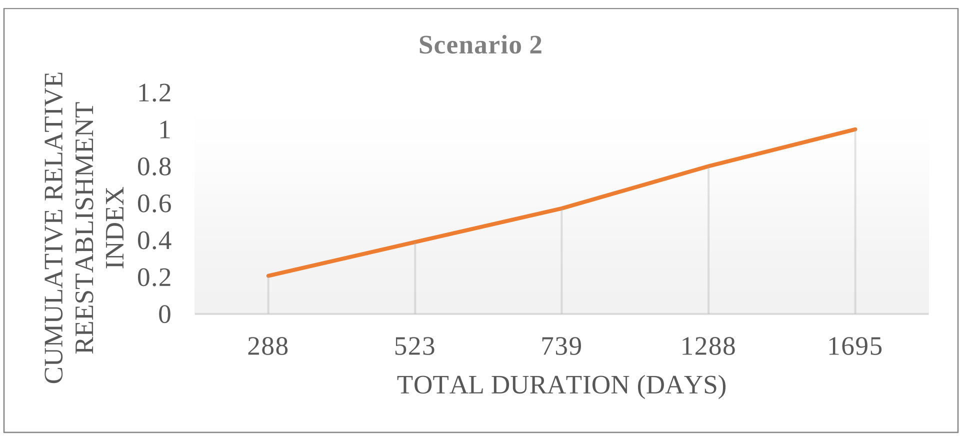

Figure 5. Cumulative relative reestablishment index for scenario 2.

Table 28. Sub-optimum solution (trial 23) results for scenario 2.

Project Sequence	Alternative #: Project/Acceleration Method	Cumulative Duration (Days)	Cumulative Relative Reestablishment Index
1	2: Project 1-Fast-track	351	0.206
2	16: Project 4-No acceleration	900	0.435
3	8: Project 2-Fast-track	1,135	0.618
4	21: Project 5-No acceleration	1,542	0.818
5	11: Project 3-No acceleration	1,907	1.000
Total duration (days)	1,907		
Total investment ($)	27,233,500		
Cumulative relative reestablishment (index)	1		
Acceleration preference (index)	0.378		

Table 29. Sub-optimum solution (trial 93) results for scenario 2.

Project Sequence	Alternative #: Project/Acceleration Method	Cumulative Duration (Days)	Cumulative Relative Reestablishment Index
1	2: Project 1-Fast-track	351	0.206
2	8: Project 2-Fast-track	586	0.389
3	12: Project 3-Crashing	802	0.595
4	16: Project 4-No acceleration	1,351	0.824
5	21: Project 5-No acceleration	1,758	1.024
Total duration (days)	1,758		
Total investment ($)	46,889,023		
Cumulative relative reestablishment (index)	1		
Acceleration preference (index)	0.333		

5.4. Decision-Making Validation and Recommendations

The research team organized a workshop with transportation professionals to show the decision-making model and share the results to collect feedback about the process and share the different perceptions and barriers faced by private transportation companies and DOTs. However, the research team believes that public entities can benefit from positive practices adopted by private transportation companies, considering the regulation constraints. Some of these practices include contract flexibility after a disaster, pre-disaster planning, and stand by contracts.

A real-world case study to validate the model built to prioritize accelerated projects after a natural hazard needs to use data from past events. One of the results of this research is that the DOTs are not able to provide the data needed for the development of a real-world case study. Consequently, it was not possible to validate the model with DOT personnel. However, during the interview process, it was identified that private railroad companies and Counties are more likely to have and provide this type of data. Therefore, the goal during the implementation phase will be to validate the model with these entities using data from past natural hazard events.

Although the institutional barriers are not objectively considered in a prioritization model to accelerate projects after a disaster, the barriers can affect, delay, and influence the reconstruction process. Considering the similarities that arose between the barriers identified in the literature and the data collection and within the literature review, it is possible to outline some recommendations that can assist the governmental agencies and departments during the reconstruction prioritization process.

- *Recommendation 1:* Considering that some places in the Region 6 experience frequent natural disasters, and that many decisions during the recovery process need to be taken in a short period, the first recommendation is planning. Planning, in this case, means plan ahead. The process to develop a plan in case of a disaster can address many of the other barriers already identified or identify new barriers. For instance, the recovery action plan can address the aspects of allocation of responsibility, coordination, communication, resources, data, and information.
- *Recommendation 2:* The availability of resources (material, equipment, and workforce) is crucial during the acceleration of projects. In this case, agencies and departments should keep records of the availability of the owned resources. Also, these entities should develop a map of external sources to contact to complement or supply resources not owned by the public entities. Another aspect involved in these mapping of external sources is the establishment of standby contracts or on-call contracts that can be used in an emergency. The record of owned resources and standby contracts with external sources is a practice adopted by the rail-road companies identified during the interviews. This practice provides them the capacity to fast mobilize resources from other places or from the site where the disaster is about to occur (e.g., standby contract with the crane renting companies).
- *Recommendation 3:* Funding is another aspect crucial during the reconstruction and recovery process, and it also plays a fundamental role in the prioritization of projects. The sources of funding, the procedures to request, mobilize, and use the funds should be identified and understood ahead.
- *Recommendation 4:* Policies and permits can limit or delay the prioritization of projects. In this way, governmental offices and departments should open a discussion about flexibility or alternatives during a disaster recovery phase. The use of Alternative Contracting Methods (ACM) to deliver projects faster was a definite barrier identified. In some states, for example, the Design-Build method that can accelerate a project is not permitted in any way.
- *Recommendation 5:* Miscommunication can damage any project/program. Communication is an important aspect of every project or program, even without the pressure to respond to a natural disaster. In a pressured situation after a natural hazard event and the involvement of different entities and departments, communication is even more important. This way, the development of a communication procedure prior to the occurrence of a hazard event and the establishment of clear communication channels would have a good impact during the process to prioritize which projects to accelerate.

6. CONCLUSIONS

This study performed a literature review and investigated the current practices to develop a model for prioritizing needs for accelerated construction after natural disaster events. The results from this study show that the input from both literature review and experts is beneficial to inform prioritization after disasters. The research focused on the transportation infrastructure components typically affected by hurricanes and flooding which commonly affect Region 6. The literature review and the conceptual decision-making model were the first phase of this research. The literature review provided the background of prioritization criteria, accelerated methods, and institutional barriers. During the next phase after the literature review and the conceptual mode, we collected expert knowledge through survey and interview to quantify the identified decision-making criteria and the accelerated methods, and qualitative perceptions about barriers during prioritization and implementation of a prioritization of infrastructure projects after a disaster. In the final step, considering collected data, we presented a prioritization model for the reconstruction of projects after natural disasters. This research benefits resiliency and emergency response planners from state DOTs by guiding identify and prioritize needs for accelerated construction after disaster events.

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APPENDIX A: QUESTIONNAIRE

1. Which State are you working in?

◯ Arkansas

◯ Louisiana

◯ New Mexico

◯ Oklahoma

◯ Texas

2. What is your Department/Agency?

◯ State DOT

◯ County/Parish

◯ FEMA

◯ US Corp of Engineers

◯ Other (please, specify) ---------------------

3. What is your role in this department and how long have you been in this role?

Role -----------------

Years of experience ------------------

4. Which transportation infrastructure assets are typically important to be accelerated after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.)?

Transportation Infrastructure	Not Important **1**	Slightly Important **2**	Moderately Important **3**	Important **4**	Very Important **5**
Roads	A	B	C	D	E
Ports	6	7	8	9	10
Rails	11	12	13	14	15
Bridges	16	17	18	19	20
Highways	21	22	23	24	25
Drainage	26	27	28	29	30
Other (Please specify)	31	32	33	34	35

5. Which project acceleration techniques do you think should be considered after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.)? (Select All) and assign a preference value for selected project acceleration techniques based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Scheduling **crashing** (Adding extra resource)	◯	
Scheduling **fast-track** (Reducing Critical path)	◯	
Scheduling **activity substitution** (Shifting crew and scheduling)	◯	
24/7 calendar (Implementing multiple work shift and/or night work)	◯	
Linear Scheduling Method (Diagram to show location and time at which a certain crew will be working on a given operation for repetitive projects)	◯	
A + B bidding (Cost (A)+time (B) bidding procedure)	◯	
Packaged multi-primes approach to contracting (Procuring a general prime contractor, and various contractors for the specialty trades of structural, etc.)	◯	
Design-build approaches (Having construction begin before the final design has been completed)	◯	
Designate a **single individual as PM** (Less formal documentation and communication improvement)	◯	
Pre-qualify bidders on basis of past schedule performance (Considering past performance of bidders on finishing projects in a timely manner)	◯	
Information technology (Application of intelligent transportation systems (ITS); Exploit web-based team collaboration system)	◯	
Automation equipment/construction **technology** (Application of 3D machine automation on asphalt pavers)	◯	
Accelerated Bridge Construction (ABC)	◯	
Relocation of utilities (Obtaining information of utilities using subsurface utility engineering (SUE) early in the design phase)	◯	
Innovative materials (Pavement type selection: using quick-curing concrete and using in-place recycling; Precast Elements)	◯	
Full closure instead of partial closure of roadway (Full closure could be used in areas where there is at least one alternative route for drivers and where volume is limited)	◯	
Work zone traffic control (Choosing traffic control plan implementing multiple work shift and/or night work; Improve traffic flow in work zone)	◯	
Right-of-way (ROW) acquisition (Taking the land from its original owner by another party, by providing a monetary compensation for the value of the property)	◯	
Lane rental approach (Contractor must rent a lane in order to close it. Creating a monetary incentive to minimize the duration of lane closures)	◯	
Public involvement (Improve customer relationships and explore innovative agreement arrangements)	◯	
Formal partnering (All parties to a project agree at the outset to adopt a cooperative approach to problem resolution to eliminate conflicts)	◯	
Other (Please specify)	◯	

6. Which criteria do you think should be considered in a prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.)? (Select All) and assign a preference value for selected criteria based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
1. Repair Issue	◯	
2. Safety	◯	
3. Social Impact	◯	
4. Asset Characteristics	◯	
5. Socioeconomic	◯	
6. Vulnerability	◯	
7. Asset Damage Cost	◯	
8. Asset Condition	◯	
9. Connectivity	◯	
10. Construction	◯	
11. Disruption	◯	
12. Economic Impact	◯	
13. Environmental Impact	◯	
14. Traffic	◯	
15. Political Impact (Government preference)	◯	
16. Regulation	◯	
17. Sustainability	◯	
18. Budget (Available Funding)	◯	
19. Other (Please specify)	◯	

7. What barriers can impede or delay the process of prioritization and implementation of accelerated transportation projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.)?

	Barriers
Prioritization	
Implementation	

8. If you are interested in hearing more about the findings of this project, please leave your contact information, and we will keep you updated.

Name --

Phone --

Email ---

Support items for Question 6

6.1. If you have selected "Repair Issue" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Repair Issue" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Repair history	◯	
Possible repair actions	◯	

6.2. If you have selected "Safety" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Safety" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Crash Data	◯	
Fatalities	◯	
Injuries	◯	
Risk	◯	

6.3. If You have selected "Social Impact" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Social Impact" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Local support	◯	
Location of vulnerable communities	◯	
Social benefits	◯	
Population	◯	
Any associated costs imposed on society as a whole	◯	

6.4. If you have selected "Asset Characteristics" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Asset Characteristics" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Age	◯	
Total service life of the structure	◯	
Foundation and site characteristics	◯	
Asset Dimensional characteristics (length, width, etc.)	◯	
Structural characteristics	◯	

6.5. If you have selected "Socioeconomic" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Socioeconomic" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Adequate housing	◯	
Equitable access	◯	
Destroyed houses and apartments	◯	

6.6. If you have selected "Vulnerability" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Vulnerability" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Seismic hazard	◯	
Soil at site	◯	
Bedrock acceleration	◯	
Magnitude of disaster	◯	
Duration of disaster	◯	

6.7. If you have selected "Asset Damage Cost" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Asset Damage Cost" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Total cost for reconstruction, casualty and loss of function	◯	
Post-EQ loss of service score	◯	
Potential cost saved through reducing the risk of future damage	◯	
Replacement Cost	◯	

6.8. If you have selected "Asset Condition" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Asset Condition" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Maintenance expenditures	◯	
Failure modes	◯	
Maintenance requirement	◯	
Damage level	◯	

6.9. If you have selected "Connectivity" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Connectivity" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Asset location	◯	
Inter-dependency of asset with the network	◯	
Accessibility	◯	
Total number of highway sections open	◯	
Major reconstruction or rehabilitation on an existing facility that will severely disrupt traffic.	◯	
Lengthy detours.	◯	

6.10. If you have selected "Construction" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Construction" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Partnerships	◯	
Innovation	◯	
Project Development	◯	
Project is critical time sensitivity?	◯	
Demolition work in the project?	◯	
Cross drain construction in the project?	◯	
Utility relocation in the project?	◯	
Travel-time for travelers in a road-network during reconstruction	◯	
Available work-troops for reconstruction	◯	
The time needed for work-troop to reconstruct damage point	◯	

6.11. If you have selected "Disruption" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Disruption" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Downtime (D)	◯	
Recovery of businesses in the city	◯	
Number of vehicles directly impacted	◯	

6.12 If you have selected "Economic Impact" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Economic Impact" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Key transportation routes for major industries such as those associated with energy development and production, agriculture, or mining	◯	
Road user costs	◯	
Vehicle operating costs	◯	
Life cycle costs	◯	
Monetary return	◯	
Traffic cost	◯	
Allocated resource	◯	

6.13 If you have selected "Environmental Impact" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Environmental Impact" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Embodied energy (EE) (Cradle to grave)	◯	
Carbon dioxide (CO2) (Cradle to grave)	◯	
Waste (Cradle to grave)	◯	

6.14 If you have selected "Traffic" as a criterion to be considered in prioritization method to accelerate projects after a natural disaster (e.g. Flooding, Earthquake, Wildfire, Hurricane, Tornado, etc.), assign a preference value to sub-criteria of "Traffic" based on scale of 1 (The Least Important) to 10 (The Most Important).

	Check Box	Preference Value (1-10)
Vehicle speed in work zone condition	◯	
User travel time	◯	
Traffic functional affect	◯	
Daily traffic	◯	
Percent of truck traffic	◯	
Freight load capacity	◯	
Passenger Traffic	◯	
Vehicle speed in normal condition	◯	

APPENDIX B: COLLECTED DATA

Question Number	Online	Online	1	2	3	4	5	6
Q1	Texas	Texas	New Mexico	Colorado	New Mexico	Region 6	New Mexico /Texas	New Mexico
Q2	FEMA	State DOT	State DOT	The Association of American Railroads	State DOT	Railroad industry	Railroad engineering Consultant (Former BNSF 37+ years)	County/ Parish
Q3_14	Supervisor EMS	president	Manager of Bridge design section	Leader researcher in railroad infrastructure	Bridge Management Engineer	Bridge engineer	Consultant/BNSF Engineering	Director of Public Works
Q3_15	15		25	30	13	17	4+/37+	18
Q4_1	Important	Slightly Important	Very Important		Very Important	Very Important	Very Important	Very Important
Q4_2	Moderately Important	Slightly Important	Very Important				Very Important	
Q4_3	Moderately Important	Not Important	Slightly Important	Very Important	Important	Very Important	Very Important	
Q4_4	Important	Not Important	Important	Very Important	Very Important	Very Important	Very Important	Important
Q4_5	Important	Slightly Important	Important		Very Important	Very Important	Important	Important
Q4_6	Moderately Important	Slightly Important	Depends	Very Important (depends on the nature; flooding)	Moderately Important	Very Important	Very Important	Very Important
Q4_7			Signs Overhead	Signal System	Airport			
Q4_7_TEXT			Moderately Important	Very Important	Important			
Q4_8				Communication			Communication	
Q4_8_TEXT				Very Important			Very Important	
Q5#1_1				10	10	2	10	8
Q5#1_2	9	4	8	Important	10	9	10	8
Q5#1_3	6		8	Important	10	5	10	9
Q5#1_4			dangerous	Important	8	7	10	9
Q5#1_5					8	1	8	5
Q5#1_6			8 (not legal in NM)		7		10	
Q5#1_7			11		7		8	9
Q5#1_8			11	Important	10		10	
Q5#1_9			8		2	10	10	10
Q5#1_10				Important	5	10	10	9
Q5#1_11	7		8		7	10		7
Q5#1_12					4		6	
ABC			9	Important	8	10		8
Q5#1_13	8			Important	7	10	10	7

Question Number	Online	Online	1	2	3	4	5	6
Q5#1_14			10	Important	3	10	9	8
Q5#1_15	2				7	2	9	9
Q5#1_16	4				10		9	10
Q5#1_17	5				9	8	8	2
Q5#1_18	1		Ø		4		7	2
Q5#1_19	10		4		5	7		9
Q5#1_20	3		not legal in NM		10	8		9
Q5#1_21				Material that can bring from other plans		collaboration of all departments and agencies	communication	Pre-qualify on call Contractors
Q5#1_21_TEXT						10	10	10
Q5#1_21				Standardization inventory and spare				
Q5#1_21_TEXT								
Q5#1_21				cranes contractors upfront				
Q5#1_21_TEXT								
Q6#1_1	5			depend on the event	8	9	9	6
Q6#1_2	10		10	10	10	10	10	10
Q6#1_3					8	5	9	7
Q6#1_4			5	Important	7	9	9	7
Q6#1_5	4		8		7		9	8
Q6#1_6	3			Important	7		8	8
Q6#1_7			7	Important	10	5	8	9
Q6#1_8			5	Important	10	8	8	5
Q6#1_9			9	Important	8	9	9	5
Q6#1_10	2			Important	5	9	8	9
Q6#1_11	9		9	Important	9	10	9	6
Q6#1_12	1		8		9	Important	9	6
Q6#1_13	8		4	Important	7	9	4	7
Q6#1_14	6		9		10	9	7	6
Q6#1_15			2		5		2	8
Q6#1_16	7		5	Important	5	9	3	7
Q6#1_17			6	Important	7	Important	9	5
Q6#1_18		4	8		8	Important	9	10

Question Number	Online	Online	1	2	3	4	5	6
Q6#1_19				business traffic that line carries				Temporary Stabilization
Q6#1_19_TEXT								8
Q6#1_19				Type of traffic				
Q6#1_19_TEXT								
Q6.1#1_1	10							
Q6.1#1_2	5							
Q6.2#1_1	7							
Q6.2#1_2	10							
Q6.2#1_3	9							
Q6.2#1_4	8							
Q6.3#1_1								
Q6.3#1_2								
Q6.3#1_3								
Q6.3#1_4								
Q6.3#1_5								
Q6.4#1_1								
Q6.4#1_2								
Q6.4#1_3								
Q6.4#1_4								
Q6.4#1_5								
Q6.5#1_1	9							
Q6.5#1_2	8							
Q6.5#1_3	10							
Q6.6#1_1	8							
Q6.6#1_2	7							
Q6.6#1_3	6							
Q6.6#1_4	9							
Q6.6#1_5	10							
Q6.7#1_1								
Q6.7#1_2								
Q6.7#1_3								
Q6.7#1_4								
Q6.8#1_1								
Q6.8#1_2								
Q6.8#1_3								

Question Number	Online	Online	1	2	3	4	5	6
Q6.8#1_4								
Q6.8#2_1								
Q6.9#1_1								
Q6.9#1_2								
Q6.9#1_3								
Q6.9#1_4								
Q6.9#1_5								
Q6.9#1_6								
Q6.10#1_1	2							
Q6.10#1_2	5							
Q6.10#1_3	6							
Q6.10#1_4	10							
Q6.10#1_5	3							
Q6.10#1_6	4							
Q6.10#1_7	7							
Q6.10#1_8	9							
Q6.10#1_9	1							
Q6.10#1_10	8							
Q6.11#1_1	8							
Q6.11#1_2	9							
Q6.11#1_3	10							
Q6.12#1_1	8							
Q6.12#1_2	10							
Q6.12#1_3	7							
Q6.12#1_4	6							
Q6.12#1_5	5							
Q6.12#1_6	9							
Q6.12#1_7	4							
Q6.13#1_1	8							
Q6.13#1_2	9							
Q6.13#1_3	10							
Q6.14#1_1	5							
Q6.14#1_2	9							
Q6.14#1_3	6							
Q6.14#1_4	10							
Q6.14#1_5	4							
Q6.14#1_6	3							

Question Number	Online	Online	1	2	3	4	5	6
Q6.14#1_7	8							
Q6.14#1_8	7							